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A Helium-Technique Experimental Study of Longitudinal Ventilation Control in Sloped, Small-Scale Tunnels

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KEYWORDS: Critical velocity, longitudinal velocity, confinement velocity, backlayering distance, tunnel slope.

INTRODUCTION

There is limited knowledge on how the slope of a tunnel can affect the smoke movement during a fire and thus how the longitudinal ventilation should be controlled. Only very few of the previous reported studies [1–3] consider the slope of the tunnel and how it affects the critical velocity, the backlayering distance and its corresponding longitudinal velocity. Based on the helium-air technique developed by Mégret & Vauquelin [3–5], several experiments in a small-scale rig (scale 1/30 of a tunnel with a section of 6 m by 9 m in full-scale) were conducted in order to study the critical velocity, backlayering distance and longitudinal velocity (confinement velocity) in a tunnel with slope. Several heat release rates were studied, ranging from 0.42-2.6 MW, under two slopes directions (uphill and downhill), and for several slope degrees.

THEORETICAL BACKGROUND

In order to reproduce several phenomena from a full-scale fire to a densimetric small-scale fire, three stages are required: first, a set of formulae based on a semi-empirical model [6] to quantify the parameters that have to be scaled down; second, the application of two sets of scaling principles based on dynamic similarities (Froude modelling) and thermal/densimetric analogy, and third and last the equivalence of the corresponding scaled smoke flow rate to a gas densimetric buoyant mixture of helium-air [5]. The experimental rig and method was validated against full-scale data for a range of 0.42-31 MW to ensure that the method met the theoretical requirement for high fidelity results.

EXPERIMENTAL PROCEDURE

A 4.7 m long model tunnel was designed to allocate a buoyant source of helium-air mixture into the model tunnel section, see Figure 1, and to allow the quantification of the involved parameters and phenomena. Furthermore the experimental rig allowed a wide range of simulated heat release rates, and it also allows for the presence of vehicular blockage. Finally, the modular wall and ceiling construction permits modification of the tunnel slope and the tunnel geometry, making the set-up ideal for parametric studies.

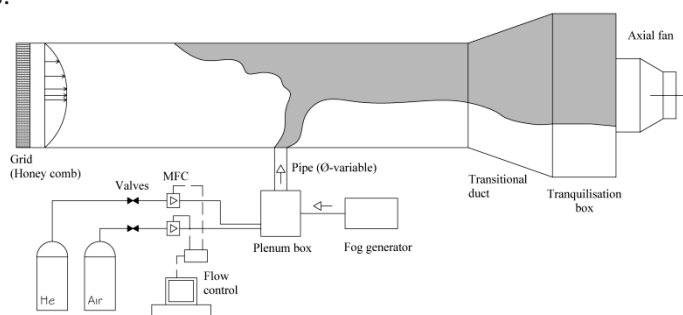


Figure 1 – Schematic view of the experimental set-up.

The buoyant mixture of helium and air gases are supplied at several flow rates, depending on the heptane pool fire size and hence the fire size. Both gases were supplied from 50 l cylinders and regulated through Bronkhorst mass flow controllers (MFC). In order to overcome the disadvantage of

the colourless buoyant mixture, the flow was seeded in a plenum box with mineral oil particles released from a fog generator. The longitudinal ventilation system was activated when the buoyant plume filled up the small-scale tunnel section, the system consisted in extracting the buoyant mixture with an axial fan (K100M) located at the end of one of the portals. A potentiometer connected to the fan allowed the regulation of the longitudinal flow. Finally an anemometer (VT100E) was used to measure the longitudinal air velocity in the middle of the model tunnel and at several locations; hence an average value was estimated.

THE CASE STUDY

A detailed experimental matrix is shown in Table 1, which contains three sets of experiments; in Set 1 the tunnel had no slope and was aimed to validate the tunnel model and the method, whereas Set 2 and Set 3 had 3% and 6% tunnel slope, respectively. For all sets the tunnel dimensions represented a full-sized tunnel with 9 m width and 6 m height, and the longitudinal ventilation control was studied uphill and downhill. One “X” means that only the critical velocity was measured, whereas “XX” means that the backlayering distance and its corresponding longitudinal velocity were measured in a first experiment, and the critical velocity in a second experiment.

Table 1 – An overview of the experiments that were carried out for several scenarios.

Source diameter (mm)	HRR (MW)	SET 1	SET 2		SET 3	
		0 % tunnel slope	3 % tunnel slope		6 % tunnel slope	
			Uphill	Downhill	Uphill	Downhill
20.7	0.42	XX	XX	XX	X	XX
26.0	0.78	XX	XX	XX	XX	XX
28.0	0.96	XX	XX	XX	X	XX
34.0	1.61	XX	X	X	XX	XX
41.0	2.62	XX	X	X	XX	XX

CONCLUSION AND FURTHER WORK

The current method and experimental set-up have been able to reproduce several phenomena in a sloped model tunnel with two orientations (uphill and downhill). Moreover the model has been validated against full-scale data for a certain range of heat release rate, from 0.42 to 31 MW.

The tunnel slope seems to have an influence on the critical velocity and backlayering distance, depending on the slope direction, uphill or downhill, where the latter affects the backlayering distance to a greater extent. However, further experiments are required to be executed with higher slope and larger HRR.

The experimental set-up has the advantage to allow a great modularity and thus several scenarios can potentially be studied. Further experiments are planned that include three stages: confinement velocity, tunnel slope and transversal ventilation control.

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